Cal Trig. Requirements

Input
- ECAL trigger towers, 0.087ϕ x 0.087η
- Matching HCAL towers
- Data every 25ns - including any corrections for time development of calorimeter signal
  - 8 bit transverse energy
  - 1 bit finegrain characterization of energy deposit
- Data presynchronized across all channels, ECAL and HCAL trigger towers with multiple crystals/tower segments

Output
- Top 4 nonisolated electrons/photons (E_t and location)
- Top 4 isolated electrons/photons (E_t and location)
- Top 4 jets (E_t and location)
- Total and missing transverse energy (E_t, E_x, E_y)
- Minimimum ionization ID and isolation bits for use with muon trigger

Outut rate
- 75 kHz maximum - half of this for calorimeter trigger
- Simulations should indicate about a factor of 3 safety margin - i.e., ~12.5 kHz

Efficiency
- Trigger should contribute no more than a few percent inefficiency for any physics channel compared to other offline analysis cuts.
- Trigger efficiencies should be measurable

Sridhara Dasu, CMS Trigger Group, UW-Madison

System

- ~4000 Gb/s serial input links
- Received by 18 Crates
- Share reduced data
- Operate synchronously
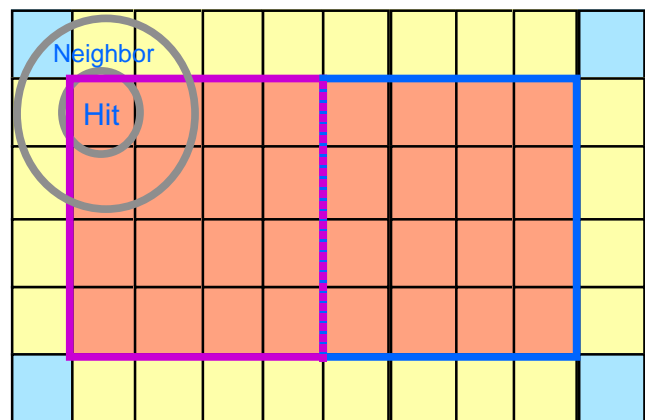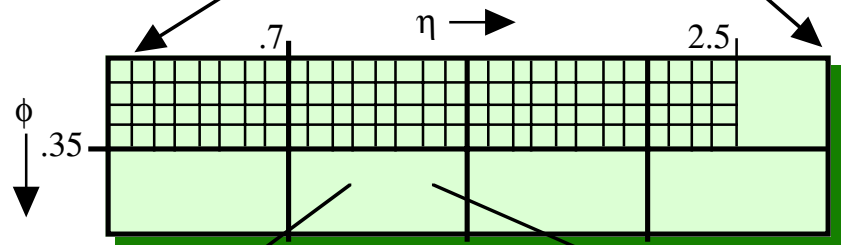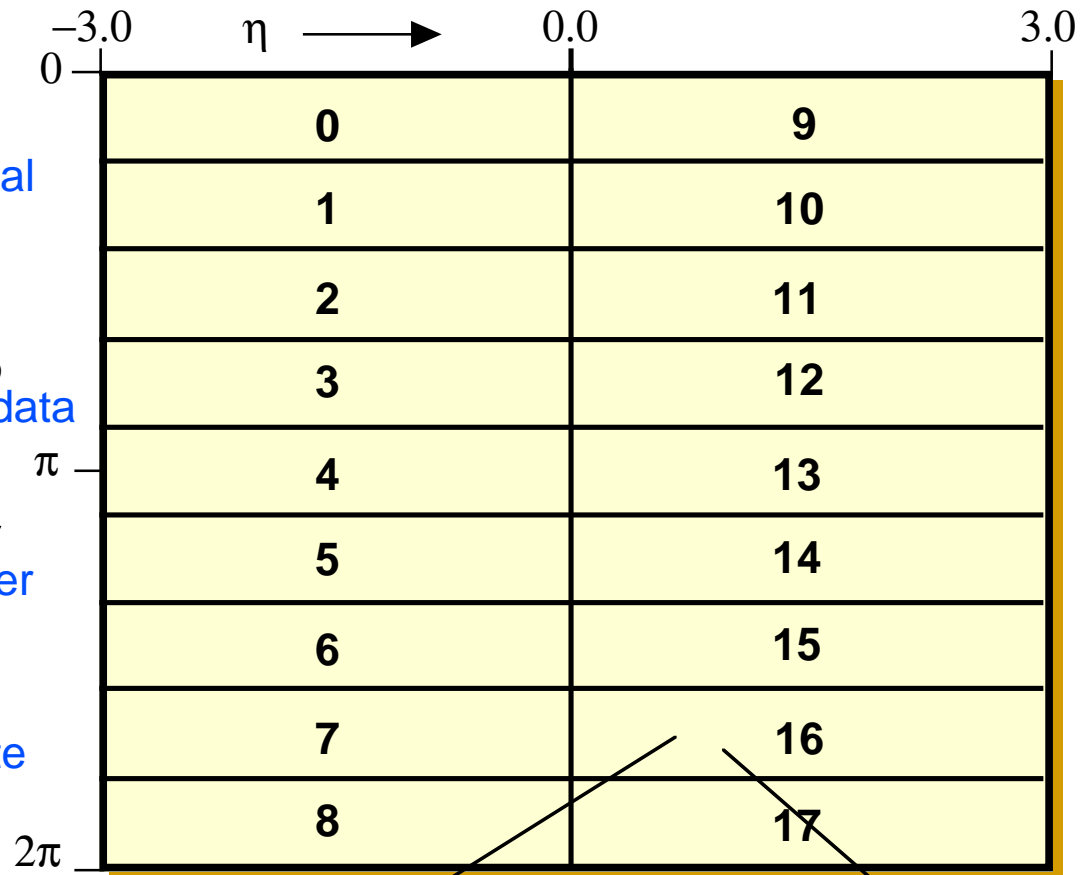- Seemlessly cover $\eta-\phi$ plane

Crate

- 256 inputs / crate
- 18 bits data per trigger tower.
- Data sharing on point-to-point 160 MHz backplane

Cards

- 32 trigger towers (E/HCAL) per card.
- Lookup tables, ASICs and ECL logic

ASICs

- Process 8 or 16 towers at 160 MHz
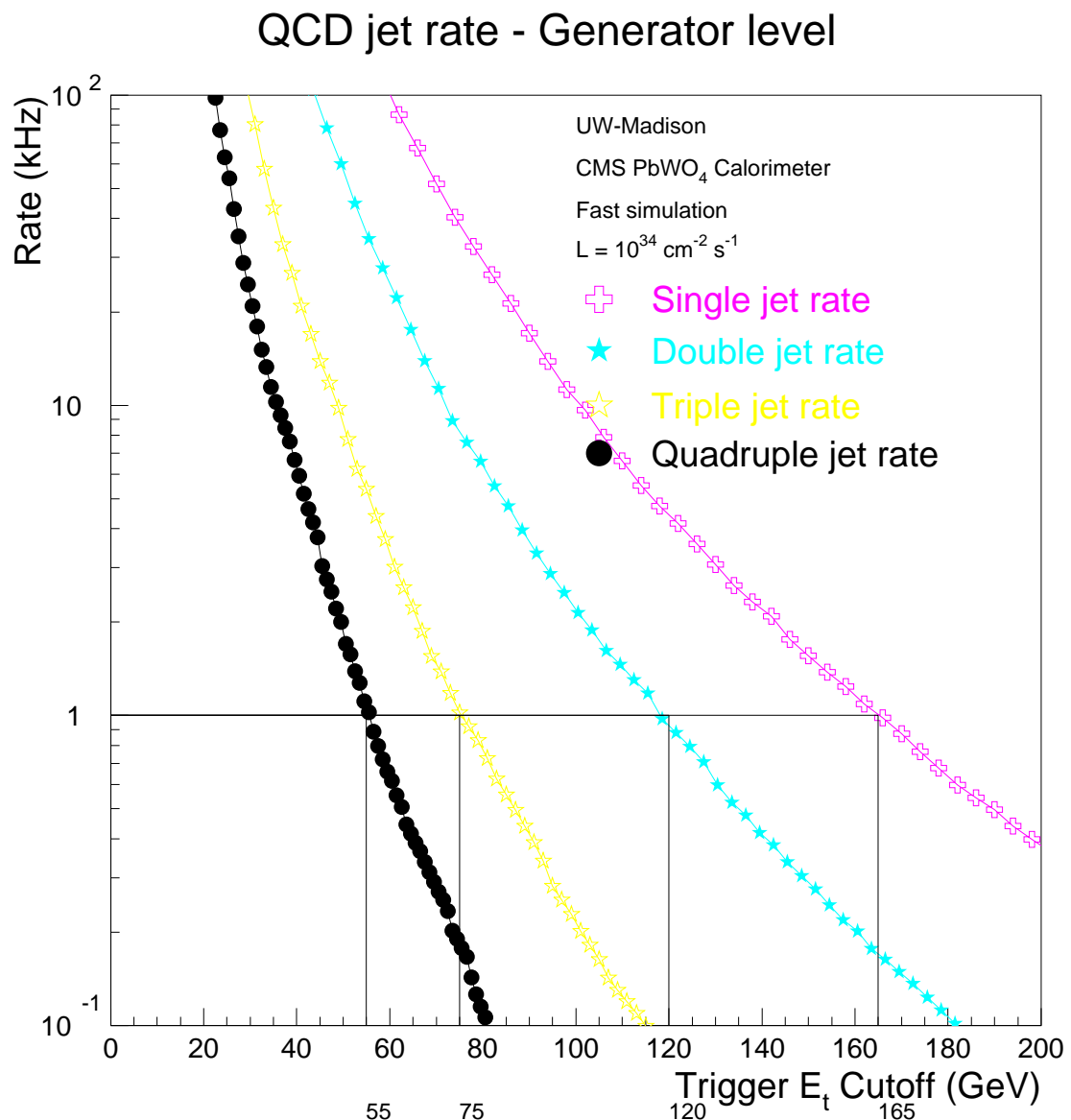- Implement adders, electron algorithm ...

Generator level jet rate

Rate to tape is 100 Hz. Level-1 output target for jets is about 3 kHz.
What is a reasonable target for jet threshold?
With a "perfect" calorimeter and trigger @ 10^{34}

- **Single jet threshold > 165 GeV**
- **Double jet threshold > 120 GeV**

The detector resolutions and algorithms degrade performance.

QCD jet rate - Generator level

UW-Madison
CMS PbWO$_4$ Calorimeter
Fast simulation
$L = 10^{34}$ cm^{-2} s^{-1}

- Single jet rate
- Double jet rate
- Triple jet rate
- Quadruple jet rate

Rate (kHz)

Trigger E$_t$ Cutoff (GeV)

55   75   120   165
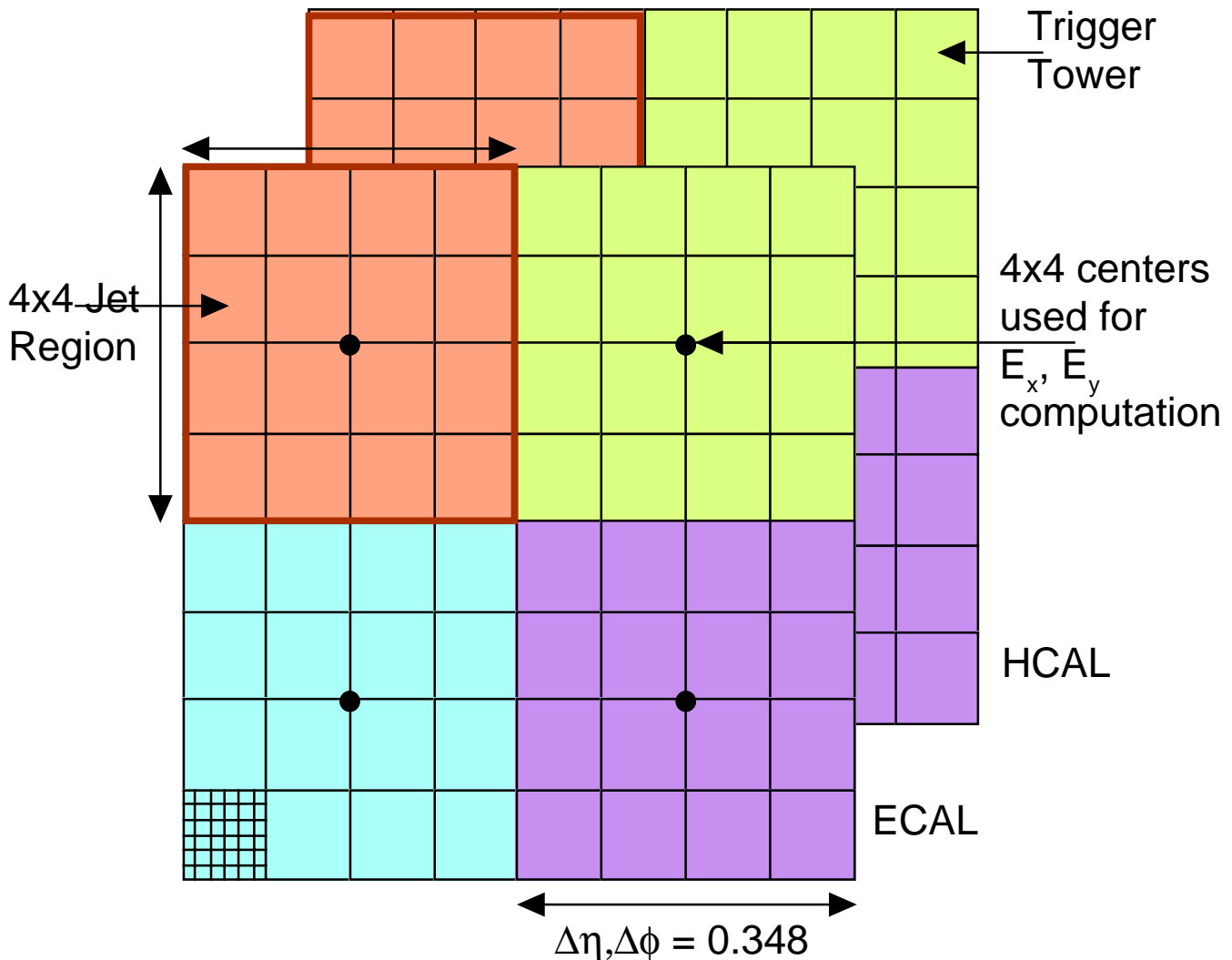
Competing factors

- **Larger the region more energy is collected.**
- **Larger the region more possibility of overlap.**
  - Overlapping regions have to be considered
  - Pruning of spurious multijet candidates needed
  - Care needs to be taken to avoid mistakes in jet counting
- **Larger the region more minimum bias pileup integrated.**
  - May have to set higher tower level cutoffs.

Technology

- **Need to sum over fixed shapes - 2x2, 4x4, 6x6, 8x8 towers**
- **Make largest possible sum at the very first card in the system to reduce data transmitted to next card.**
- **Jet overlap processing requires more fancy logic and data sharing between cards.**

Trigger Tower

4x4 centers used for E$_x$, E$_y$ computation

4x4 Jet Region

HCAL

ECAL

$\Delta\eta, \Delta\phi = 0.348$

Jet E$_t$ is given by the sum of ECAL and HCAL trigger tower E$_t$ in a non-overlapping 4x4 region

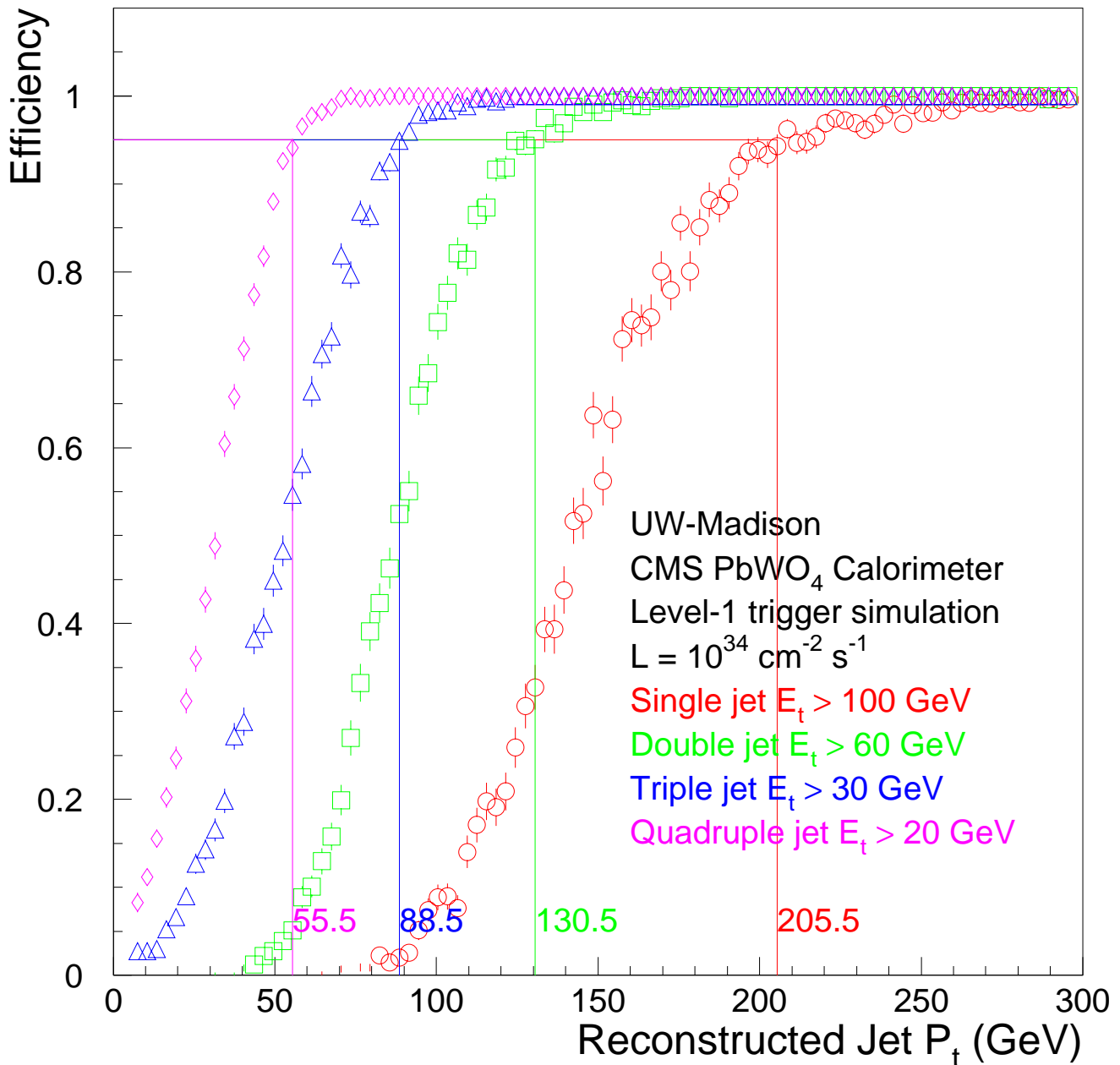**Jet candidates are sorted to find highest energy jets**

Jet trigger is caused by core of the physical jet. This allows for jet counting without the problems of dealing with multiple jets overlapping in large (0.1ηx0.1ϕ) regions

E$_x$ and E$_y$ are obtained by a memory lookup using 4x4 E$_t$ Signed E$_x$ and E$_y$ sums over the entire calorimeter are made to calculate missing E$_t$

Jet trigger efficiency

QCD jet efficiency - 4x4 algorithm

UW-Madison
CMS PbWO$_4$ Calorimeter
Level-1 trigger simulation
$L = 10^{34}$ cm^{-2} s^{-1}
Single jet E$_t$ > 100 GeV
Double jet E$_t$ > 60 GeV
Triple jet E$_t$ > 30 GeV
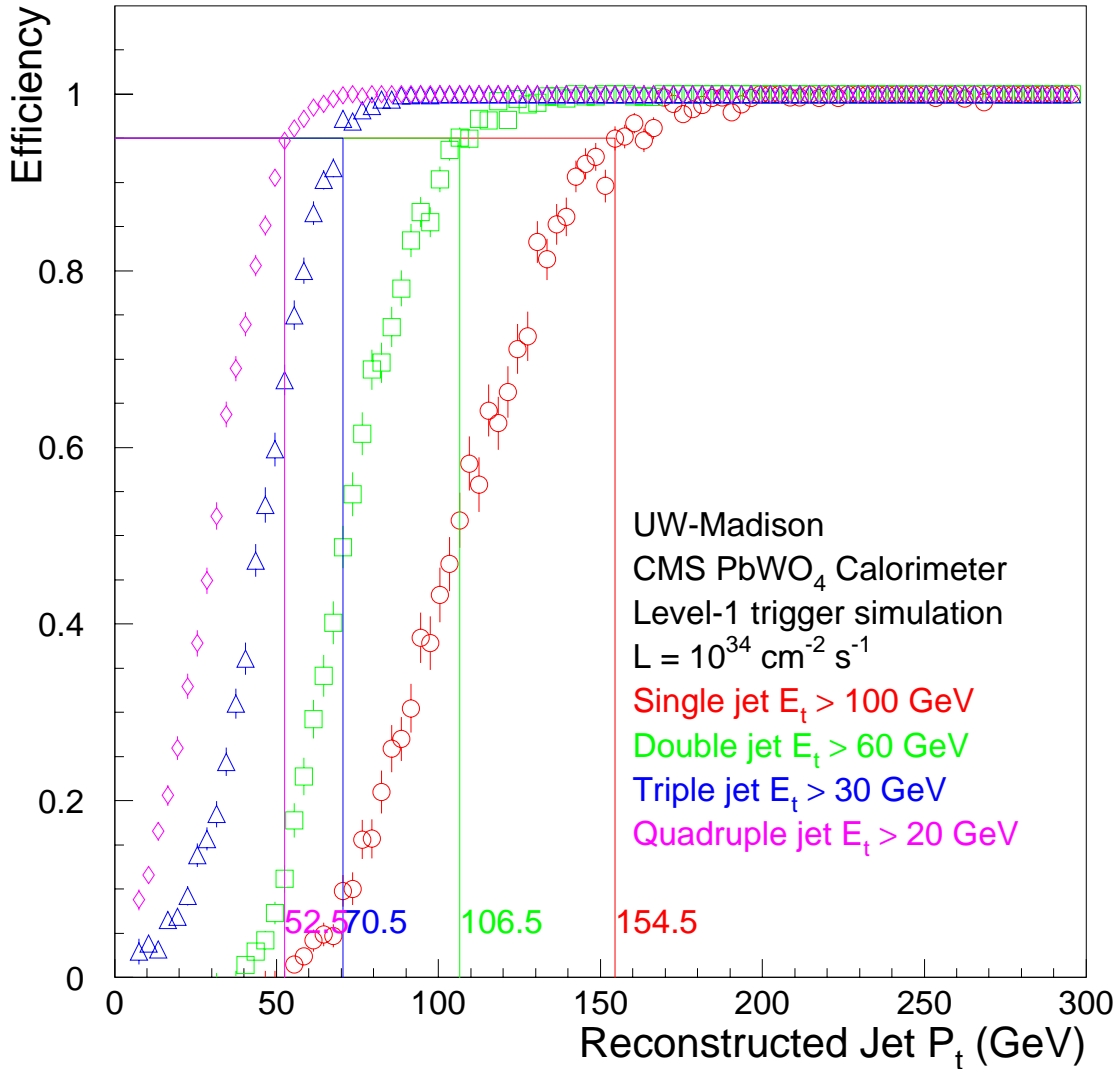Quadruple jet E$_t$ > 20 GeV

Jet trigger efficiency plotted versus particle level reconstructed jet P$_T$

Cumulative efficiency for multi-jet triggers plotted versus smallest of the reconstructed jet P$_T$

Combined jet trigger efficiency

QCD jet efficiency - 4x4 algorithm (all four jet cuts)

UW-Madison
CMS PbWO$_4$ Calorimeter
Level-1 trigger simulation
$L = 10^{34}$ cm^{-2} s^{-1}
Single jet E$_t$ > 100 GeV
Double jet E$_t$ > 60 GeV
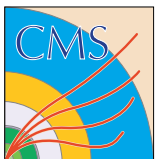Triple jet E$_t$ > 30 GeV
Quadruple jet E$_t$ > 20 GeV

Combined jet trigger efficiencies - i.e., if any of the single, double, triple or quadruple region cuts is passed, it is a "jet trigger".

Single jet == Highest jet Pt formed using generated hadron Pt
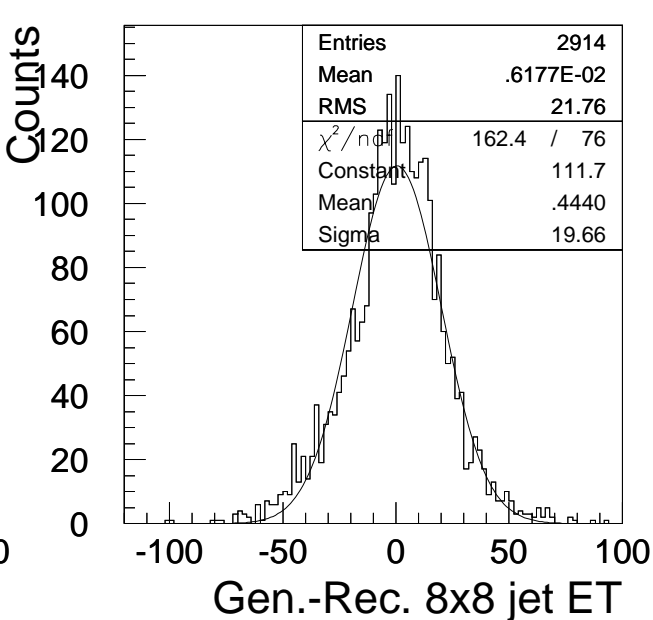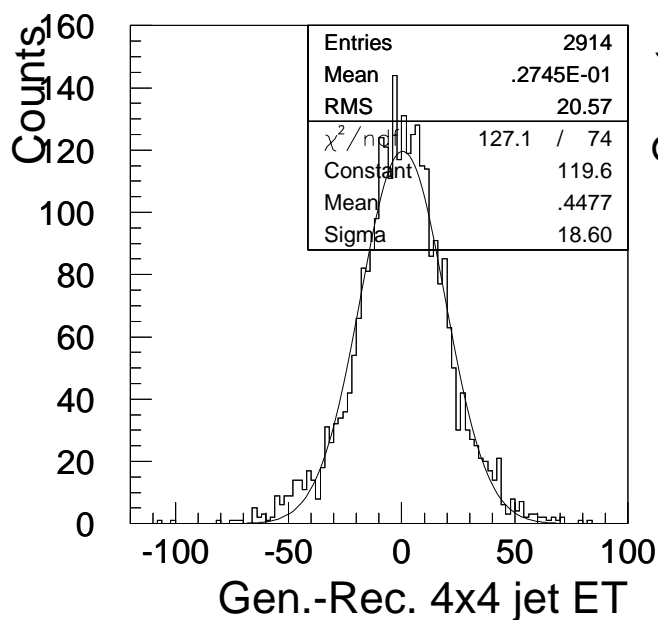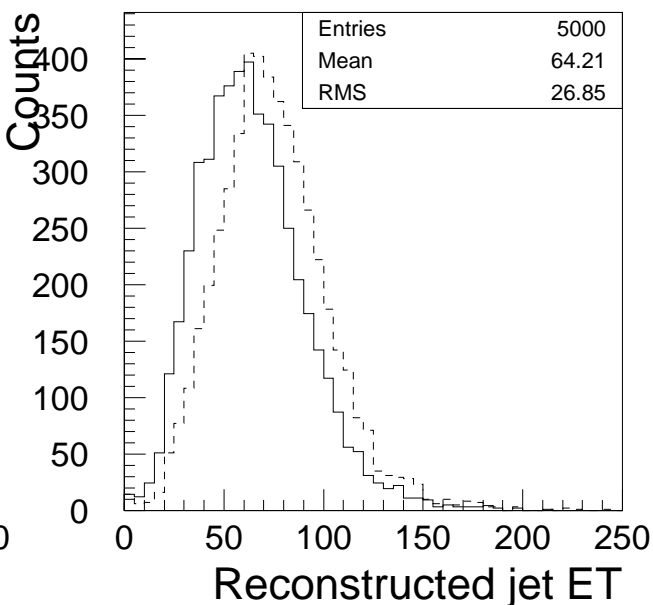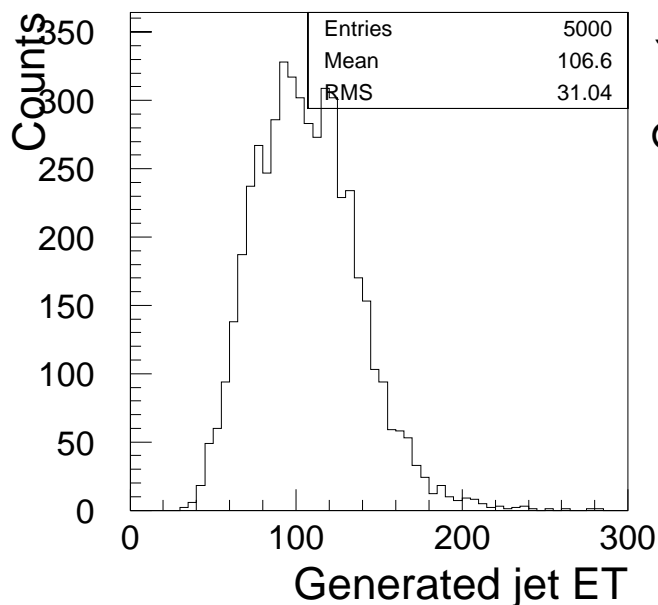Double jet == Second highest jet Pt
Triple jet == Third highest jet Pt
Quadruple jet == Fourth highest jet Pt
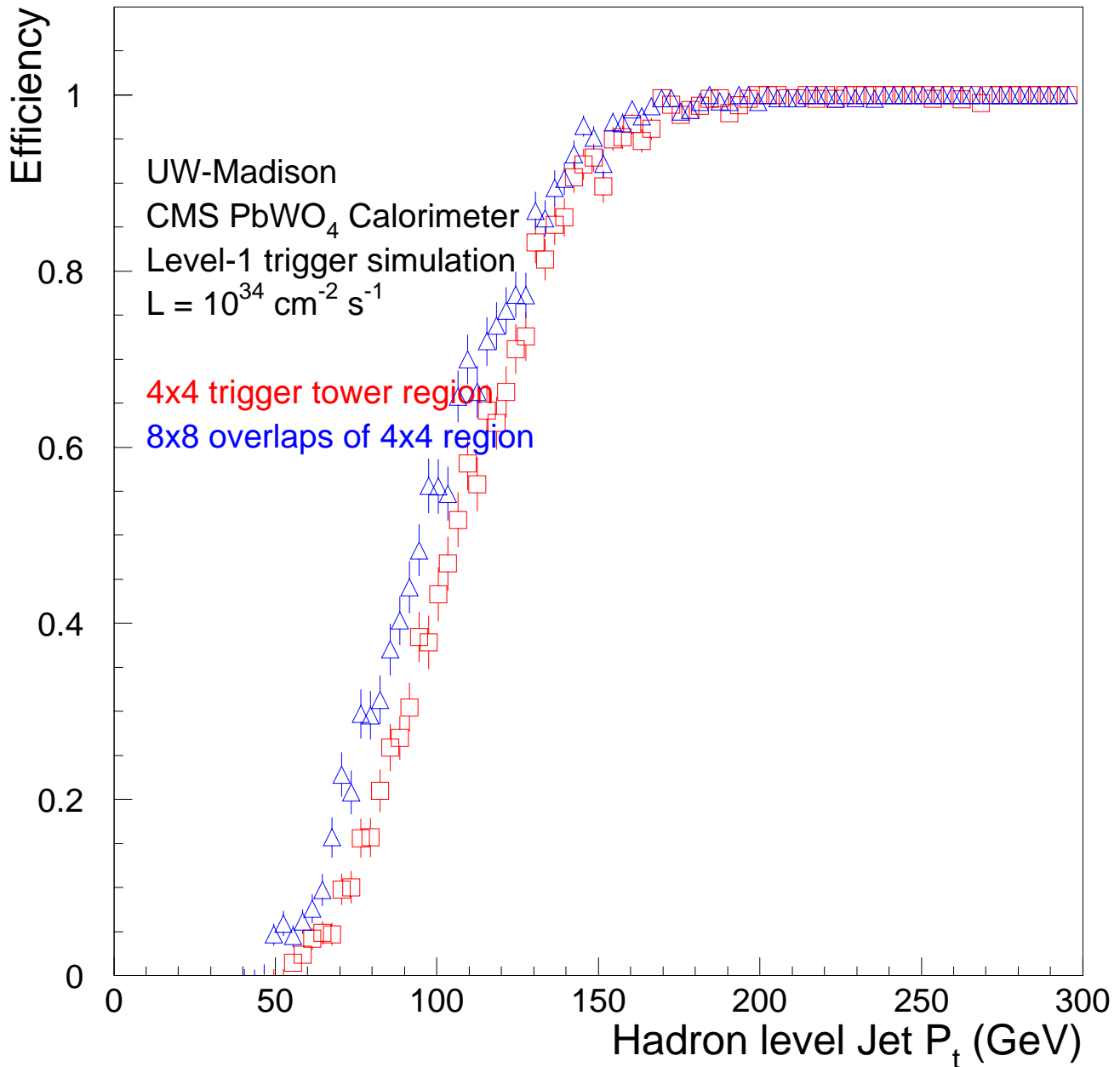
Jet resolution

Jet Energy Resolution

Level-1 jet energies compared to hadron level jets
- Not all energy is collected in the jet region
- No big improvement in resolution due to 8x8 overlaps
- Expected resolution is 100%, i.e. 10 GeV versus 19 GeV seen.
- Resolution is worsened by about a factor of 2 due to trigger cutoffs.

Comparison of jet algorithms

Single Jet Efficiency (All four jet cuts) Comparison

UW-Madison
CMS PbWO$_4$ Calorimeter
Level-1 trigger simulation
$L = 10^{34}$ cm^{-2} s^{-1}

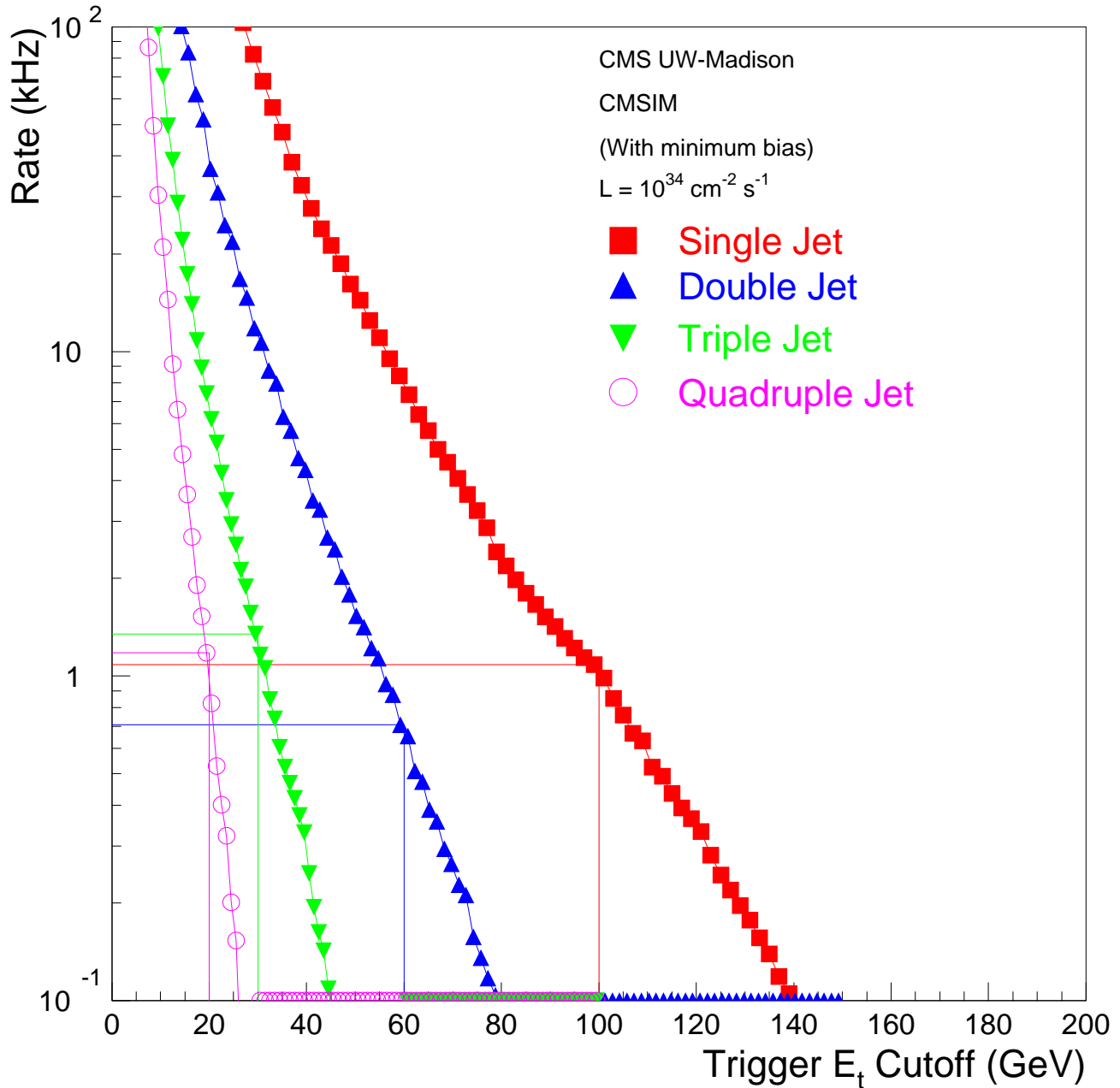4x4 trigger tower region
8x8 overlaps of 4x4 region

Overlapping jet trigger has slightly better efficiency turn on but it
comes at a significant price. Our judgement is that it is not worth it.
- Big increase in intercrate sharing
- More complex logic to purge overlapping jets
- Simple logic to purge overlaps resulted in poor jet counting

Sridhara Dasu, CMS Trigger Group, UW-Madison

Jet trigger rates

Incremental jet trigger rates

CMS UW-Madison

CMSIM

(With minimum bias)

$L = 10^{34} \; cm^{-2} \; s^{-1}$

- ■ Single Jet
- ▲ Double Jet
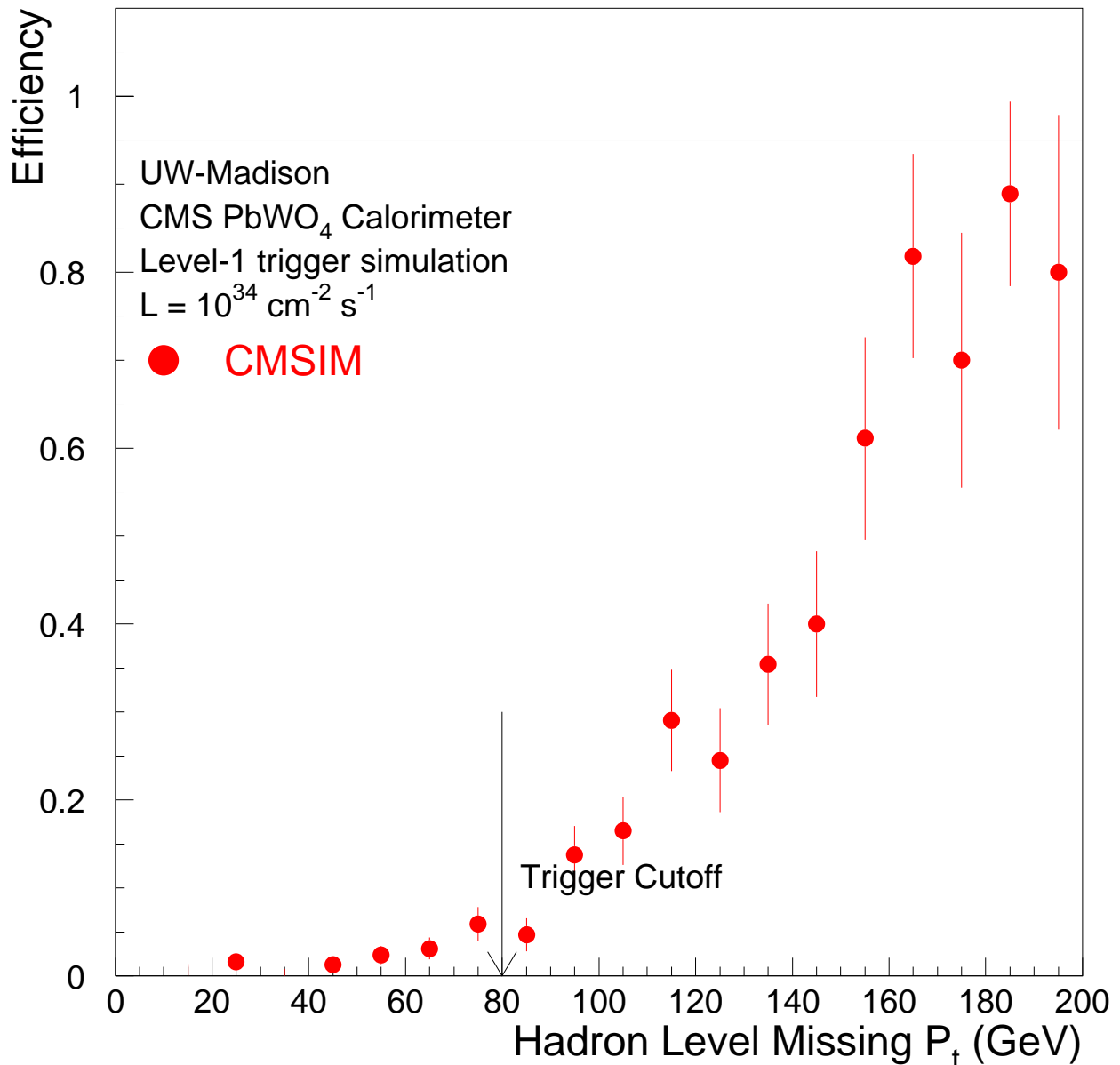- ▼ Triple Jet
- ○ Quadruple Jet

Integrated trigger rate above the trigger E_T cutoff is plotted versus the E_T cutoff.

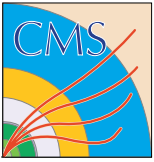Multijet rates are incrementally over lower multiplicity triggers.

Missing E_T efficiency

Missing E_T Trigger at $L = 10^{34}$ cm^{-2} s^{-1}

UW-Madison
CMS PbWO$_4$ Calorimeter
Level-1 trigger simulation
$L = 10^{34}$ cm^{-2} s^{-1}

● CMSIM

Trigger Cutoff

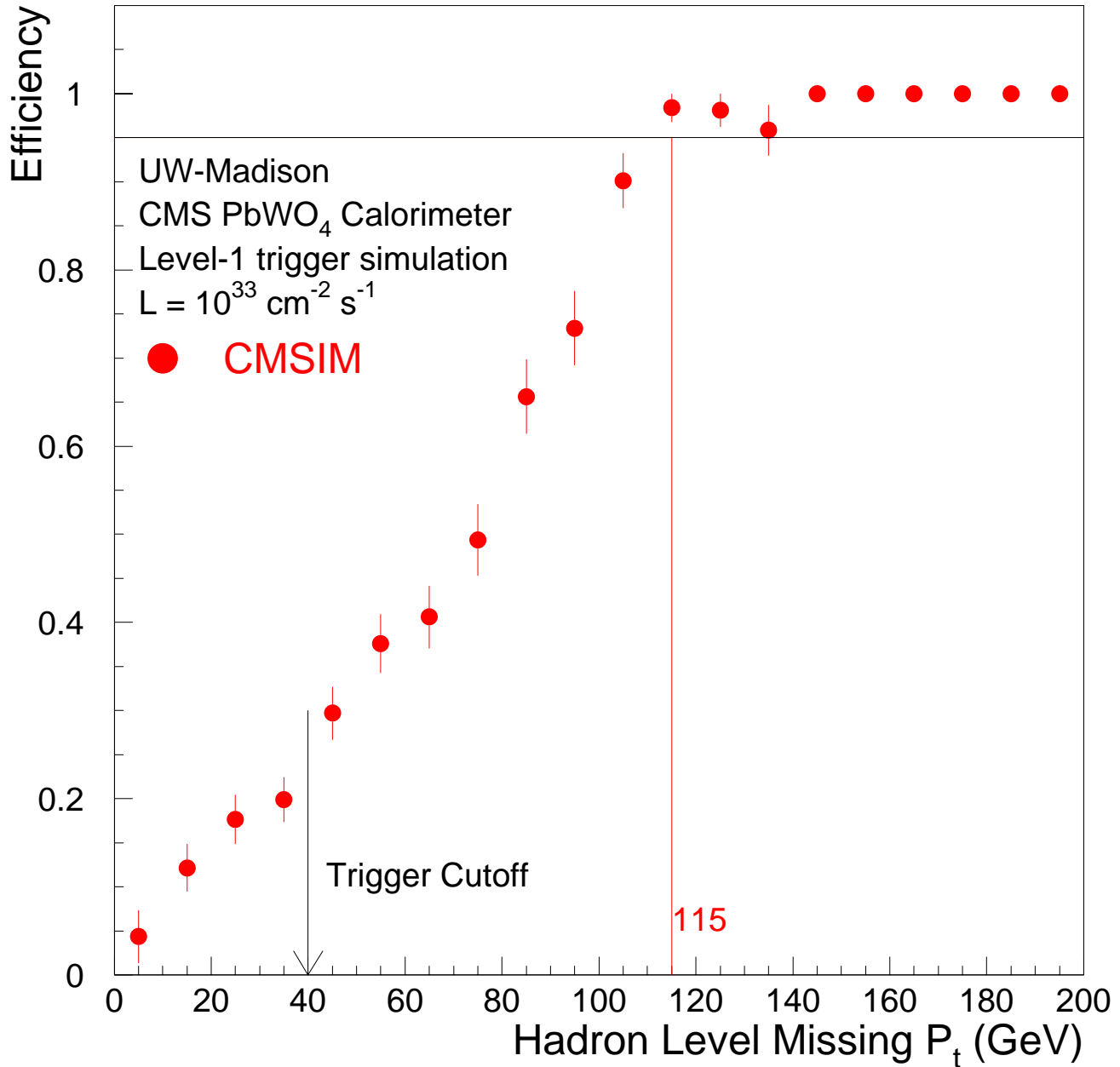ISASUSY events - plotted versus generated hadron level missing E_T

Rather slow turn-on of efficiency
- Resolution worsening due to various components studied in fast simulation earlier - need to repeat this with CMSIM.
- Only a ~25% due to level-1 trigger compromises

Missing E_T efficiency - low luminosity

Missing E_T Trigger at $L = 10^{33}$ cm^{-2} s^{-1}

UW-Madison
CMS PbWO$_4$ Calorimeter
Level-1 trigger simulation
$L = 10^{33}$ cm^{-2} s^{-1}

● CMSIM

Trigger Cutoff
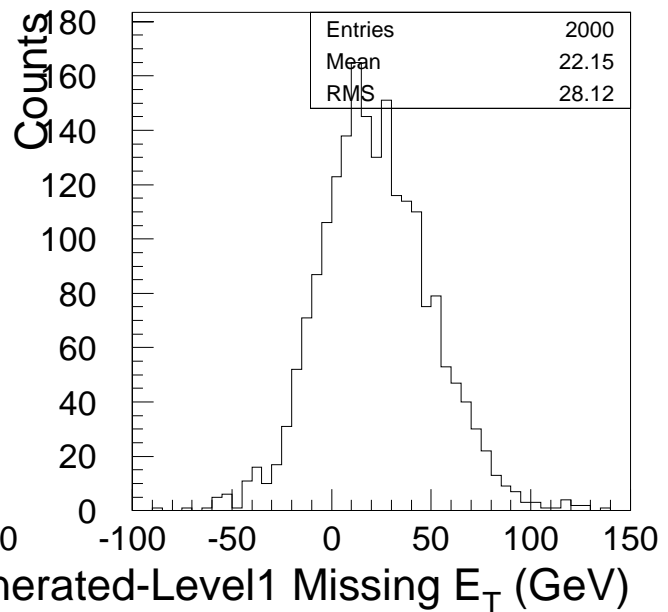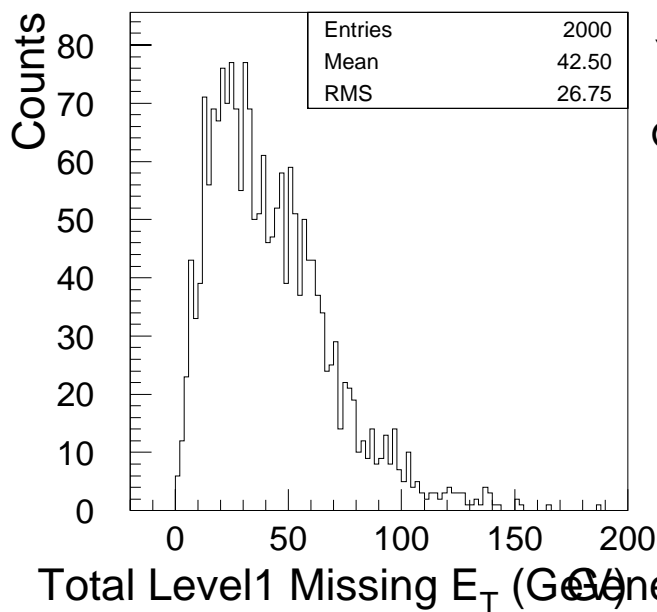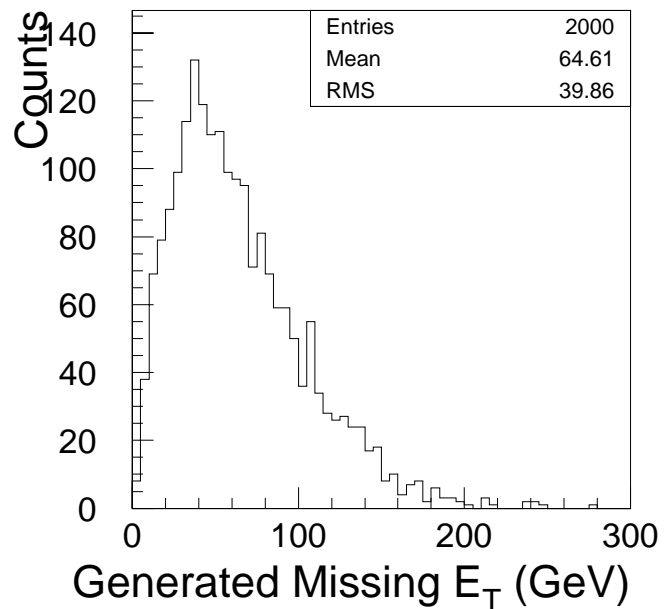
115

Efficiency

Hadron Level Missing P_t (GeV)

Well, it eventually reaches full efficiency

Missing E_T resolution (SUSY)

Missing E_T resolution for SUSY(M_{spart}=300GeV) events
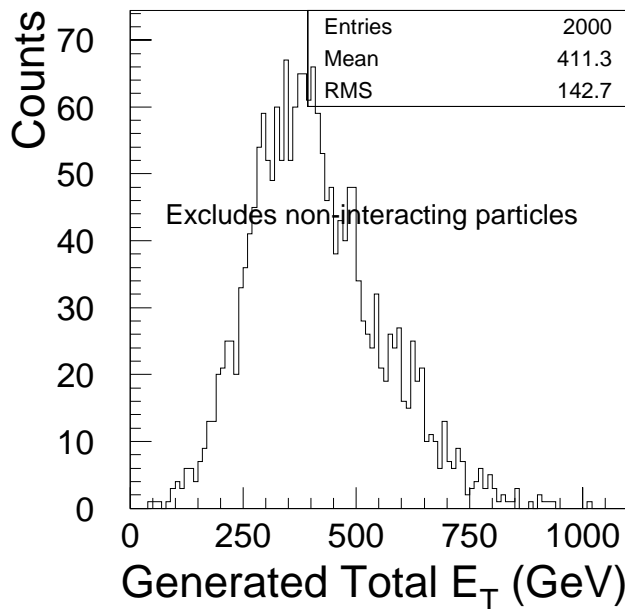
Expected resolution of 100% * Sqrt(TotalET) is about what you see even at trigger level

Missing E_T resolution in QCD events

Total and missing E_T resolution at **CMSIM HIT**level
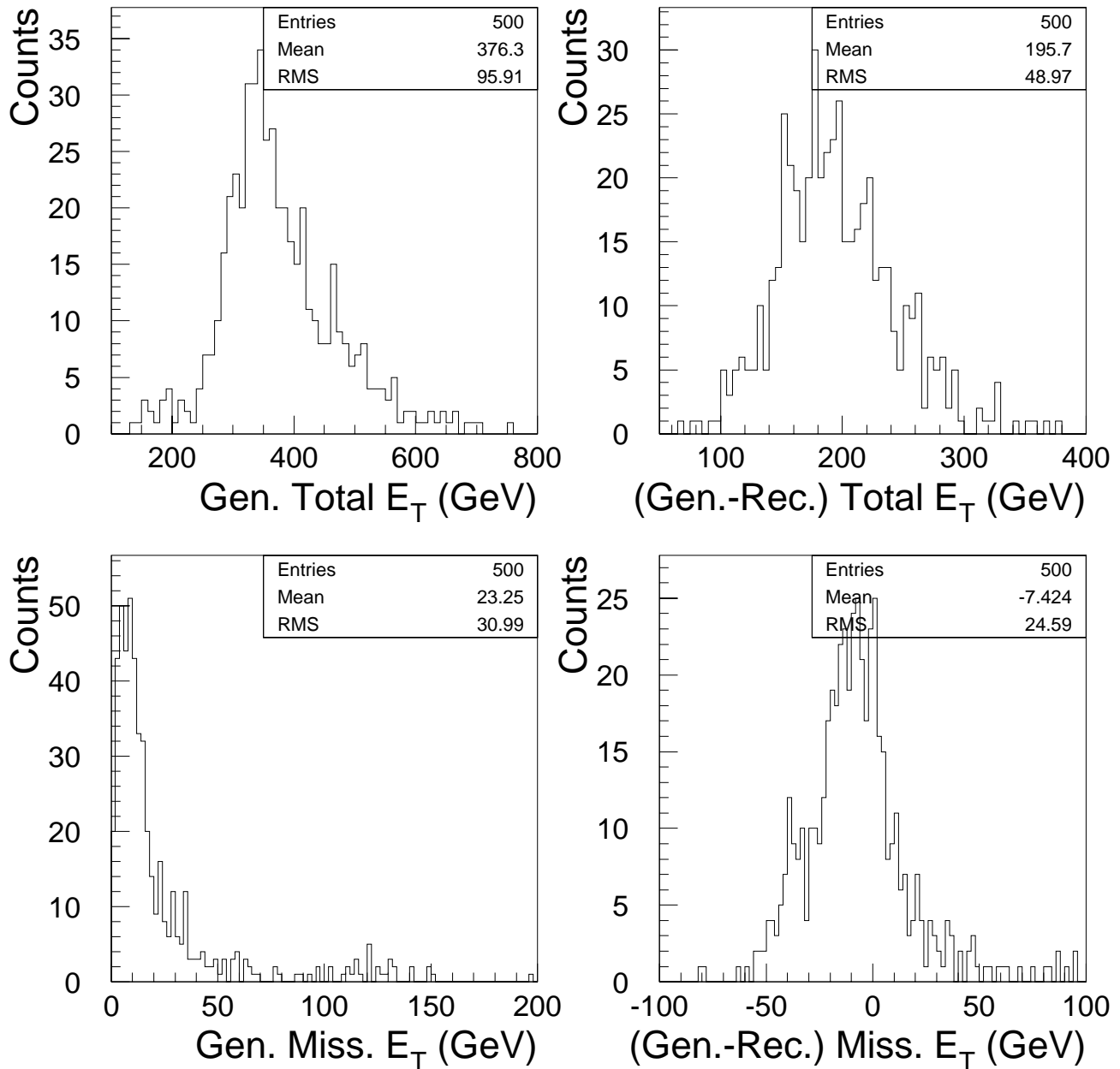
Missing E$_T$ resolution in QCD events

Total and missing E$_T$ resolution at **L1 Trigger** level

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Missing Et trigger rate

UW-Madison

CMS PbWO$_4$ Calorimeter

CMSIM

L = 10^{34} cm^{-2} s^{-1}

● Without VFCAL

High Luminosity Rate Table

For a sample set of trigger cuts emphasising e/γ channel

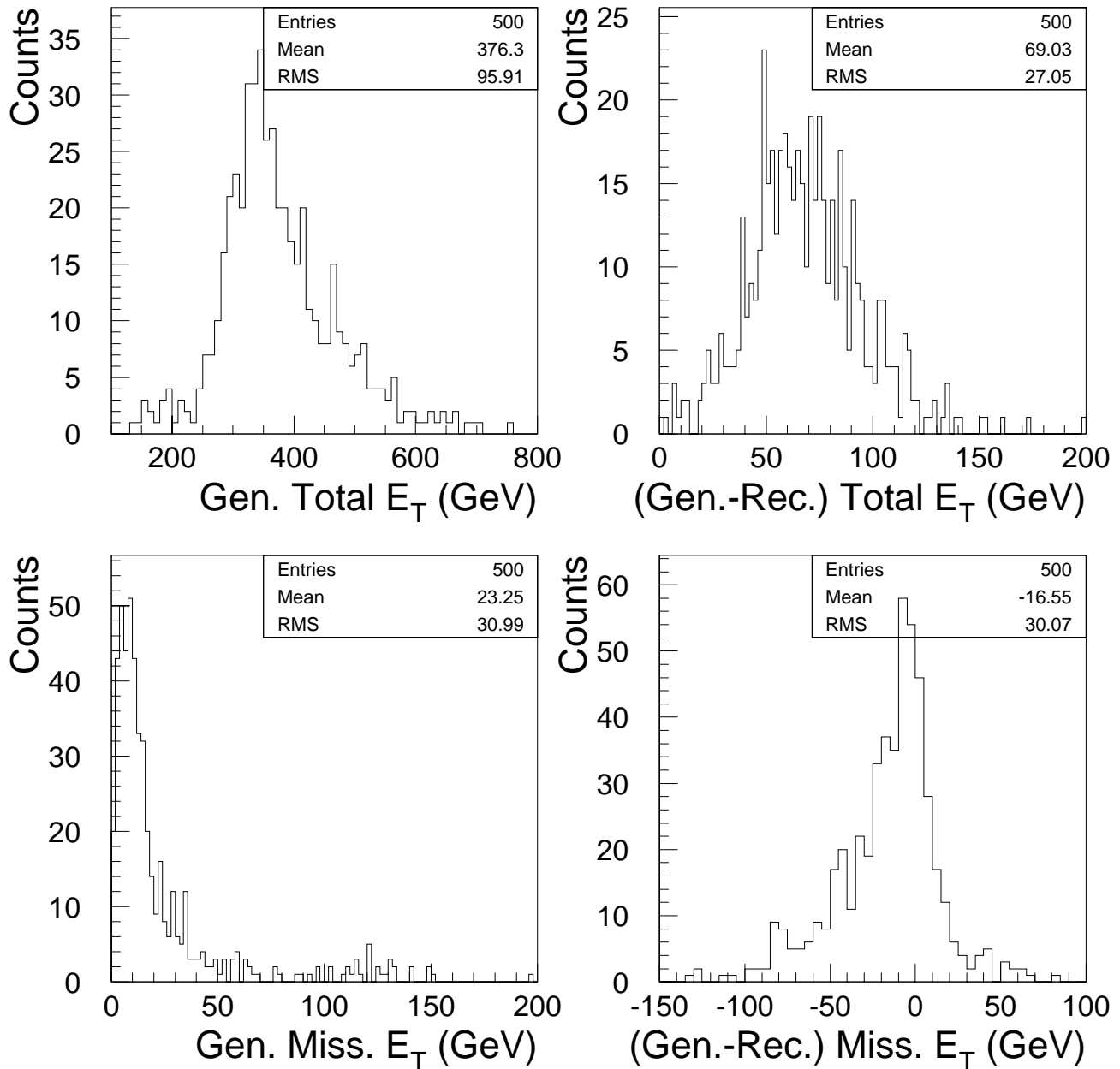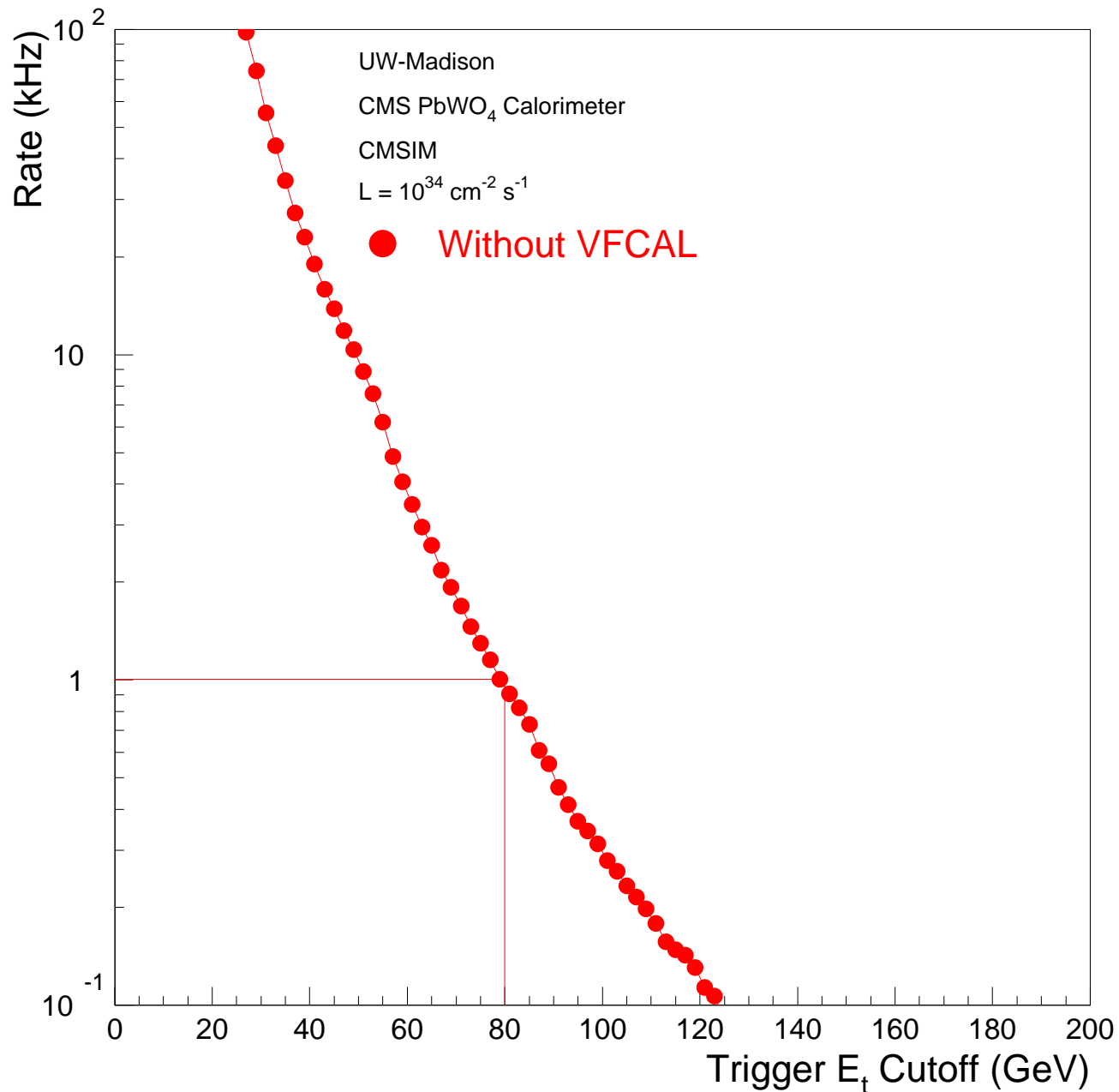| Trigger Type	Trigger E_T Cutoff (GeV)	95% Efficiency Threshold (GeV)	90% Efficiency Threshold (GeV)	Incremental Rate (kHz)
Sum E_T	400			0.3
Missing E_T	80		200	0.9
Electron	27	35	33	5.3
Dielectron	14	22	20	1.3
Single jet	100	155	142	1.0
Dijet	60	106	100	0.7
Trijet	30	70	65	1.3
Quadjet	20	52	49	1.0
Jet + Electron	50 & 14			0.3
Cumulative Rate (kHz)	12.1			

Table 1: E_T cutoffs, 95% and 90% efficiency turn-on thresholds and incremental rate are shown for a variety of triggers at $\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}.

- **The trigger cutoffs are fully programmable.**
  - Can be tuned to yield desired efficiency.
- **The total rate is required to be ~12.5 kHz.**
  - Nominal Level-1 75 kHz rate is shared equally by muon/calorimeter subsystems. Further a safety factor of 3 to account for the limited reliability of rate predictions.

Low Luminosity Rate Table

For a sample set of trigger cuts emphasising e/γ channel

Trigger Type	Trigger E_T Cutoff (GeV)	95% Efficiency Threshold (GeV)	90% Efficiency Threshold (GeV)	Incremental Rate (kHz)
Sum E_T	150			1.0
Missing E_T	50	110	105	0.7
Electron	16	24	20	7.3
Dielectron	8	15	12	3.0
Single jet	50	107	100	0.3
Dijet	35	77	68	0.1
Trijet	20	52	49	0.2
Quadjet	15	40	35	0.04
Jet + Electron	30 & 10			0.2
Cumulative Rate (kHz)	12.8			

Table 2: E_T cutoffs, 95% and 90% efficiency turn-on thresholds and incremental rate are shown for a variety of triggers at $\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}.

- **The trigger cutoffs are fully programmable.**
  - Can be tuned to yield desired efficiency.
- **The total rate is required to be ~12.5 kHz.**
  - Nominal Level-1 75 kHz rate is shared equally by muon/calorimeter subsystems. Further a safety factor of 3 to account for the limited reliability of rate predictions.

Physics Efficiencies High & Low Luminosity

10^{34}

Process	Efficiency (%)	
	Nominal E_T Cutoffs	Reduced rate E_T Cutoffs
H (80 GeV) $\to \gamma\gamma$	93	91
H (120 GeV) $\to ZZ \to ee\mu\mu$	76	73
H (200 GeV) $\to ZZ \to eejj$	95	95
$pp \to tt \to eX$	82	82
$pp \to tt \to eH^+ X_1 \to e\tau X_2$	76	76

Level-1 calorimeter trigger only

QCD Background Rate   16.5 kHz   12.5 kHz

Table 4: Nominal and rate descoped efficiencies are shown for a variety of physics processes relevant at high luminosity.

10^{33}

Process	Efficiency (%)	
	Nominal E_T Cutoffs	Reduced rate E_T Cutoffs
$pp \to tt \to eX$	98	97
$pp \to tt \to eH^+ X_1 \to e\tau X_2$	94	94
SUSY Squark and Gluino production CMS Technical Proposal Scenario A $M_{LSP} = 45$ GeV, $M_{spart} \approx 300$ GeV	82	77
SUSY Neutral Higgs $10 \leq \tan\beta \leq 30$ $100 \leq M_{A,H} \leq 400$ GeV	40 - 96	38 - 96

QCD Background Rate   16.5 kHz   12.5 kHz

Table 5: Nominal and rate descoped efficiencies are shown for a variety of physics processes relevant at low luminosity.

SUSY A decays to two tau.

Mass of A	tan beta	Low lumi efficiency (%)	High lumi efficiency (%)
100	15	44	15
100	30	38	13
120	10	52	19
200	15	76	37
200	30	76	33
300	30	93	62
400	30	96	76

Contribution from electron and jet triggers.
Events generated with the restriction that the taus be within
2.5 in eta and they decay in non-muonic mode only.
Low luminosity efficiencies are quite acceptable.
High luminosity efficiencies for low mass are very low.
Do we need to improve this?
Can we improve it at reasonable expense?